Whence, multiplying both sides by (n):

$$(19) \qquad \frac{CLN}{h^{3}/^{2}} = \frac{P}{h^{3}/^{2}} = .000106n - .0000009376n^{2} - .00000000266n^{3}.$$

If we now multiply both sides by $h^{3}/^{2}$ we have—

$$(20) \qquad P = h^{3}/^{2}(.000106n - .0000009376n^{2} - .00000000266n^{3}).$$
$$= h(.000106N - 0000009376N^{2} - .00000000266N^{3}).$$

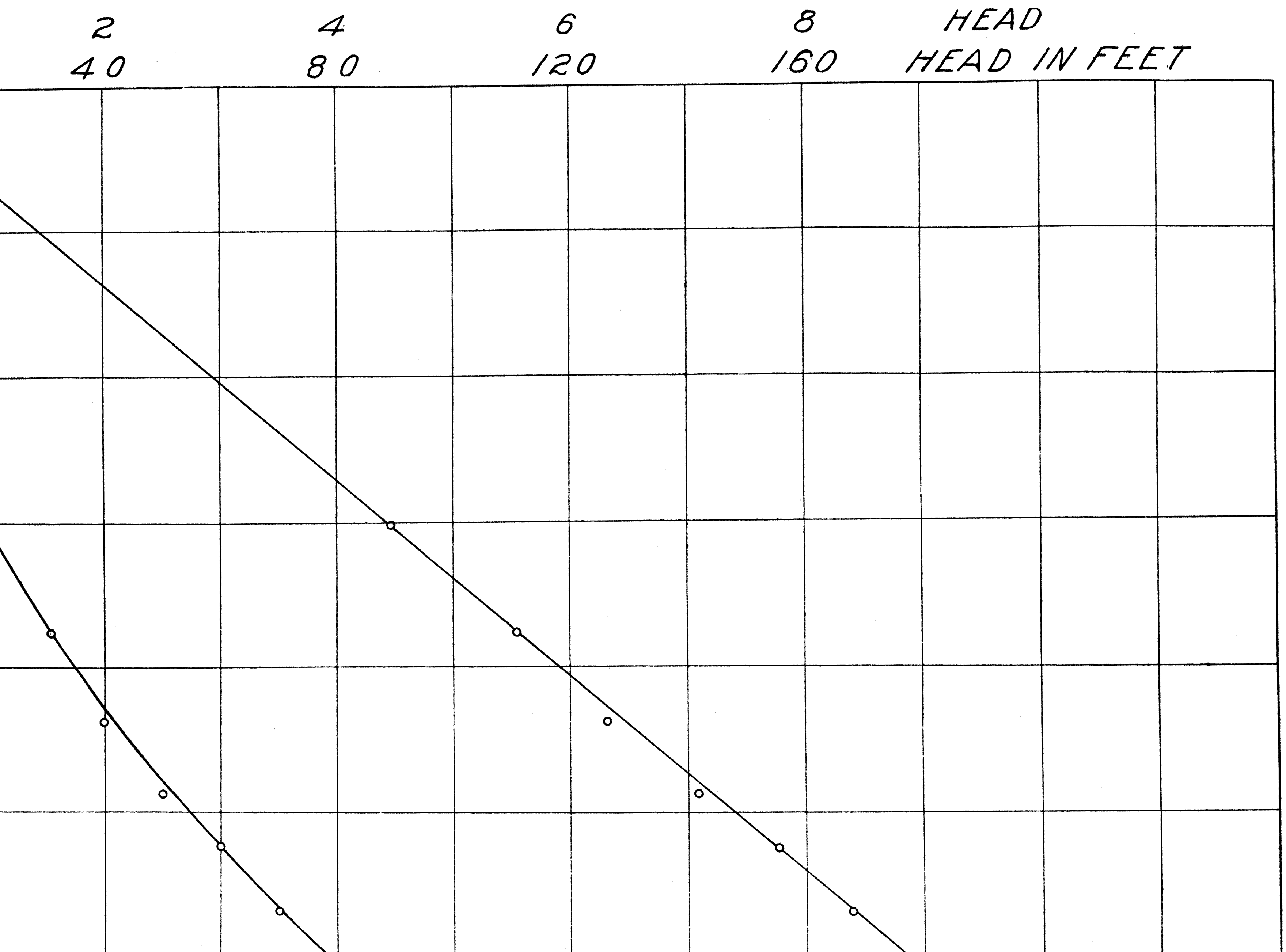
An equation which will apply directly to the wheel tested and to wheels built on the same lines and with dimensions proportional. The same form of equation can be worked out for different makes of wheels.

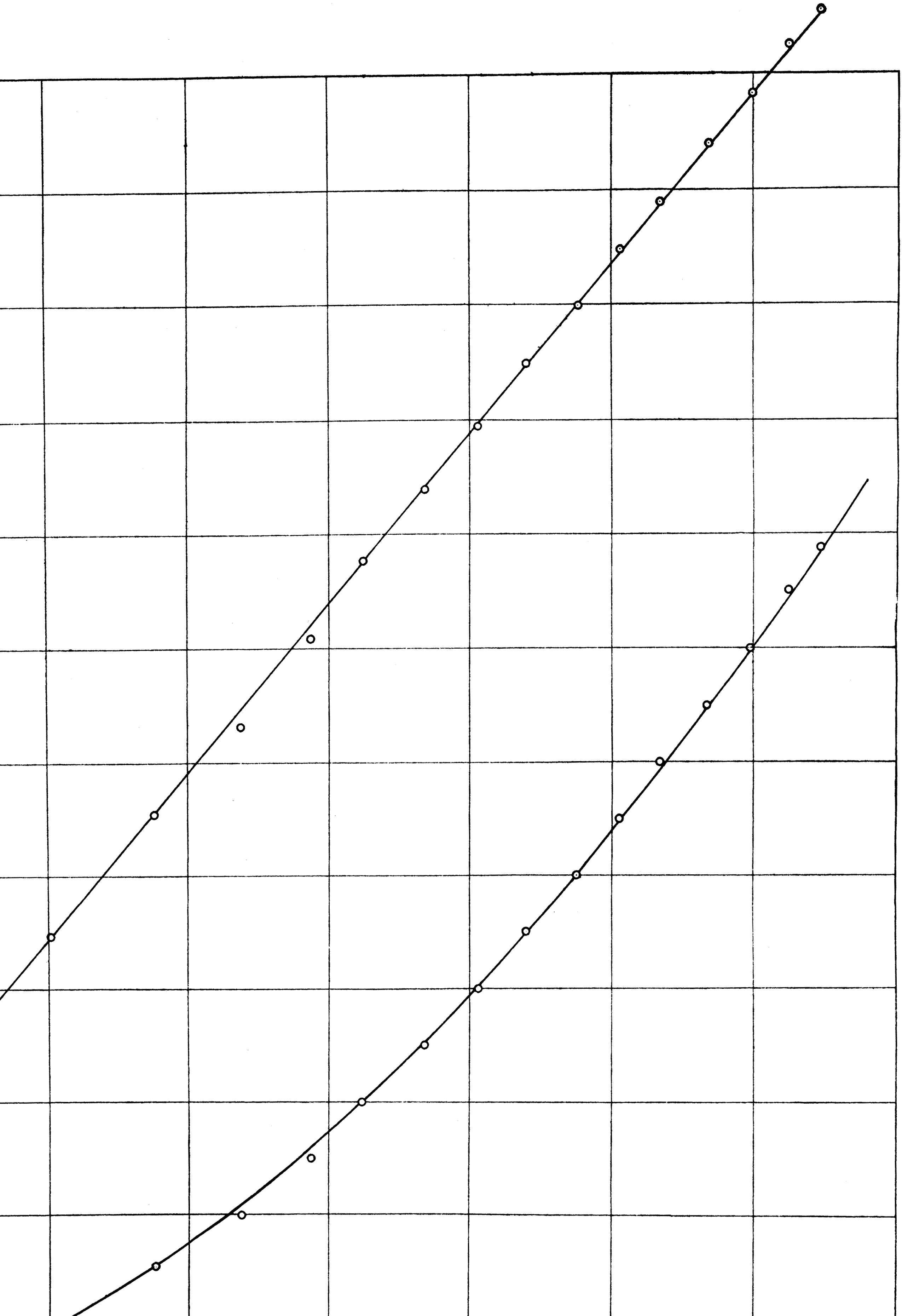
PRELIMINARY REPORT ON AN INVESTIGATION OF COAL-MINE EXPLOSIONS.

By E. HAWORTH and C. M. YOUNG, University of Kansas, Lawrence.

THE investigation of the causes of coal-mine explosions. of which this is a preliminary report, was commenced in 1906 by the Kansas State Geological Survey. In that year Lawrence Brett, one of the seniors at the University of Kansas, took this as the subject for his graduation thesis, and did a considerable amount of work, with the expectation of continuing the work later. Lack of funds has prevented the accomplishment of anything further until the present year. In the spring of 1908 Prof. Erasmus Haworth, state geologist, decided to devote the larger part of the funds at the disposal of the Survey to a continuation of this investigation. This paper is to be considered as only a preliminary report, as the investigations discussed are not completed and others are to be undertaken. But we desire to make known some of the results which have been accomplished and to make a statement of plans for the future.

The work has been divided into two distinct classes; the first literary, the second experimental. Along the first line, what might be called a literary bureau has been established and an extensive correspondence carried on with many people connected with the coal-mining industry both in this country and in Europe. A list of questions dealing with the subject was sent to a large number of coal-mine operators. Many replies have been received and the results have been tabulated. These questions were intended to elicit all possible information on the conditions of the coal-mining industry in the different coal-fields of the United States, with the idea of learning what conditions may render possible the occur-


2
4
6
8
HEAD
40
80
120
160
HEAD IN FEET



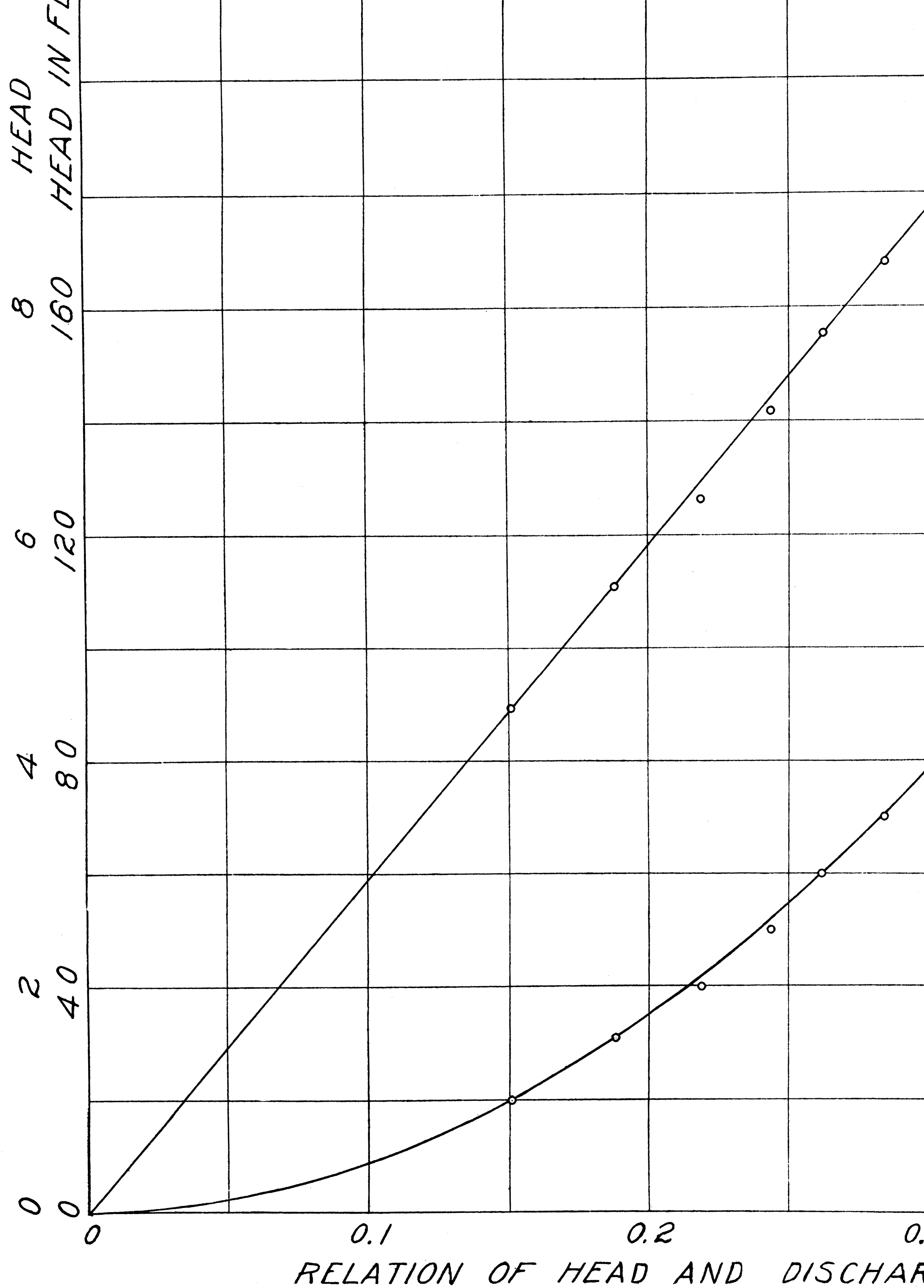
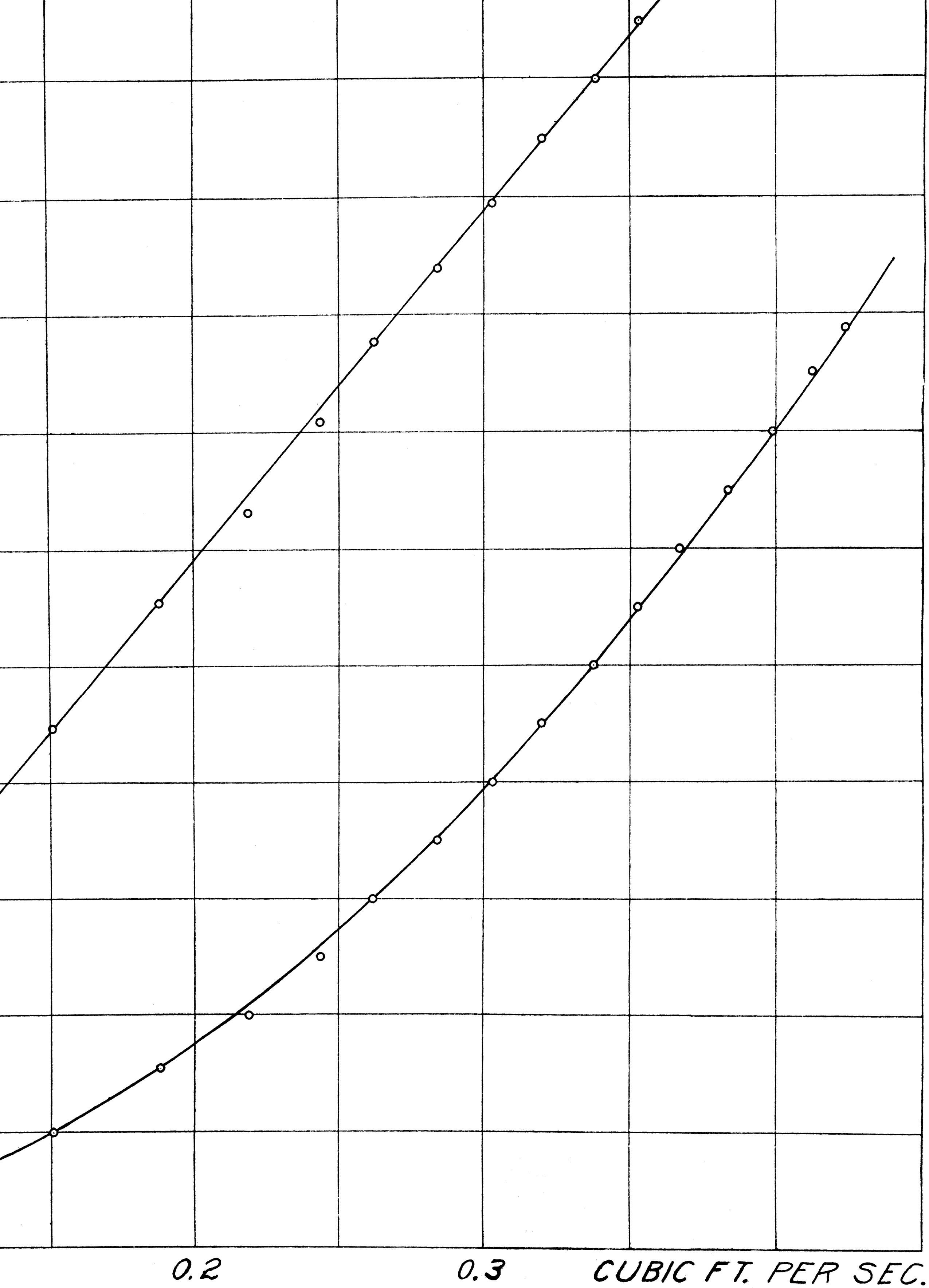
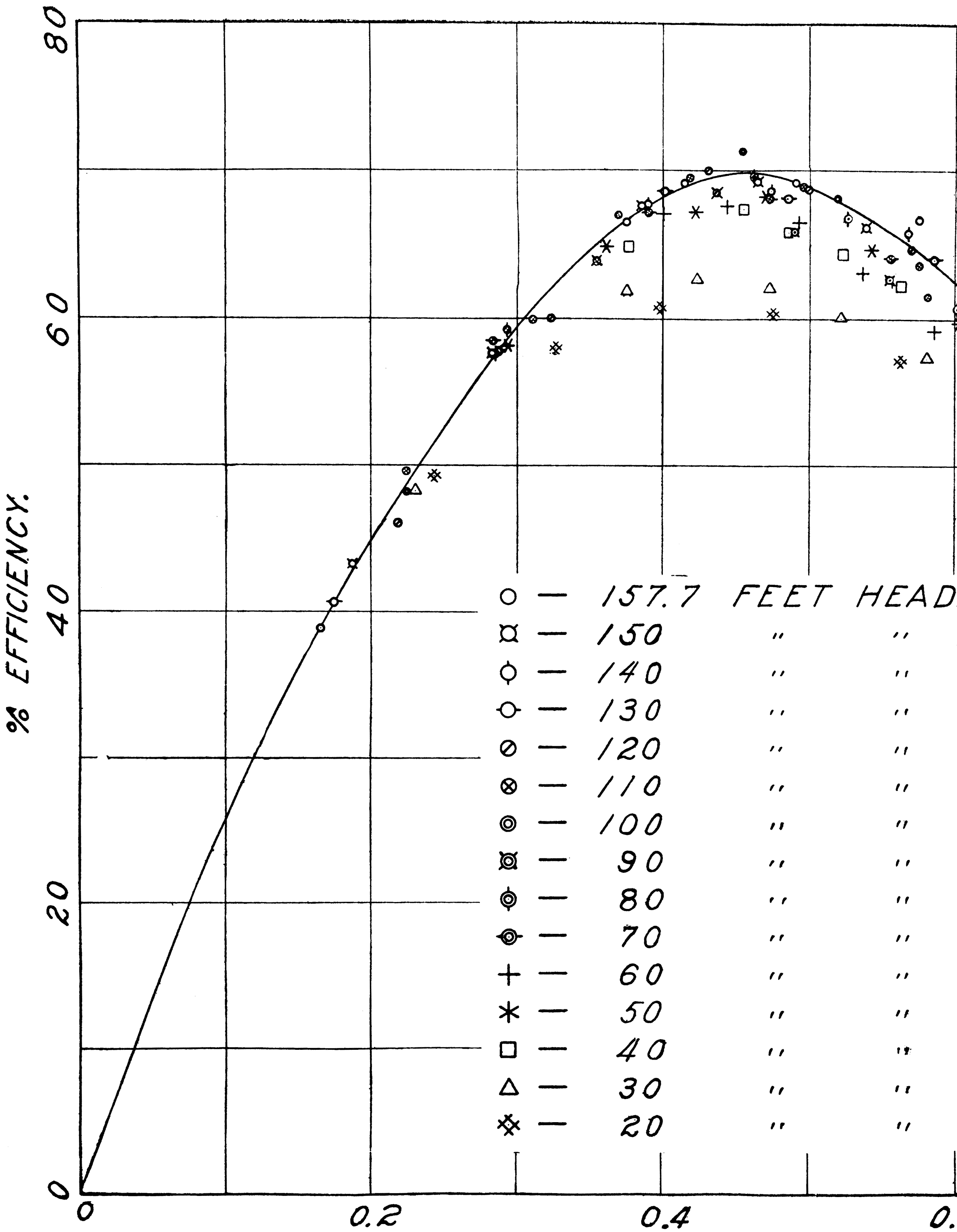

HEAD
HEAD IN FE
8
160
6
120
4
80
2
40
0
0
0
0.1
0.2
RELATION OF HEAD AND DISCHAR

FIG. I.



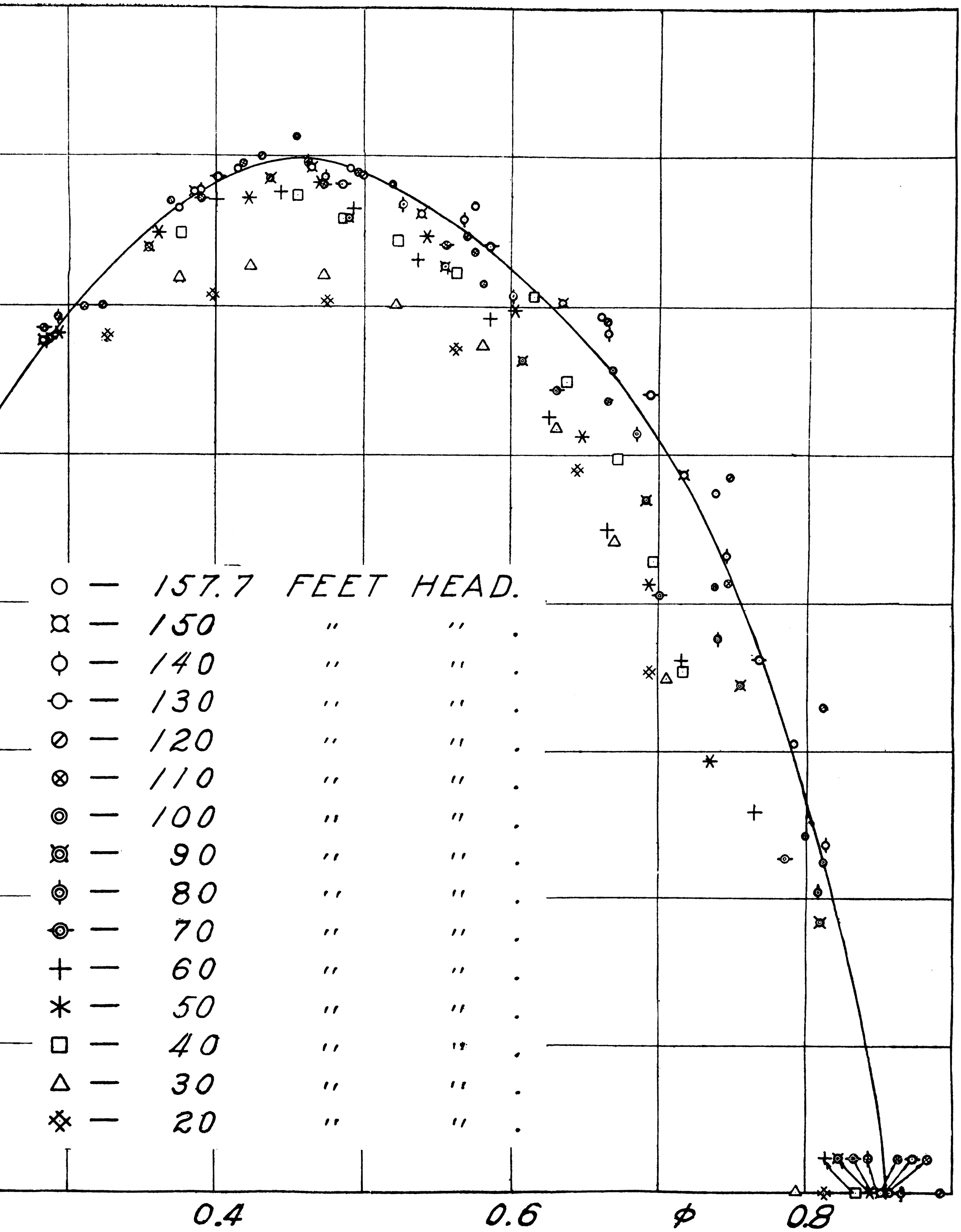
OF HEAD AND DISCHARGE.

FIG. 1.



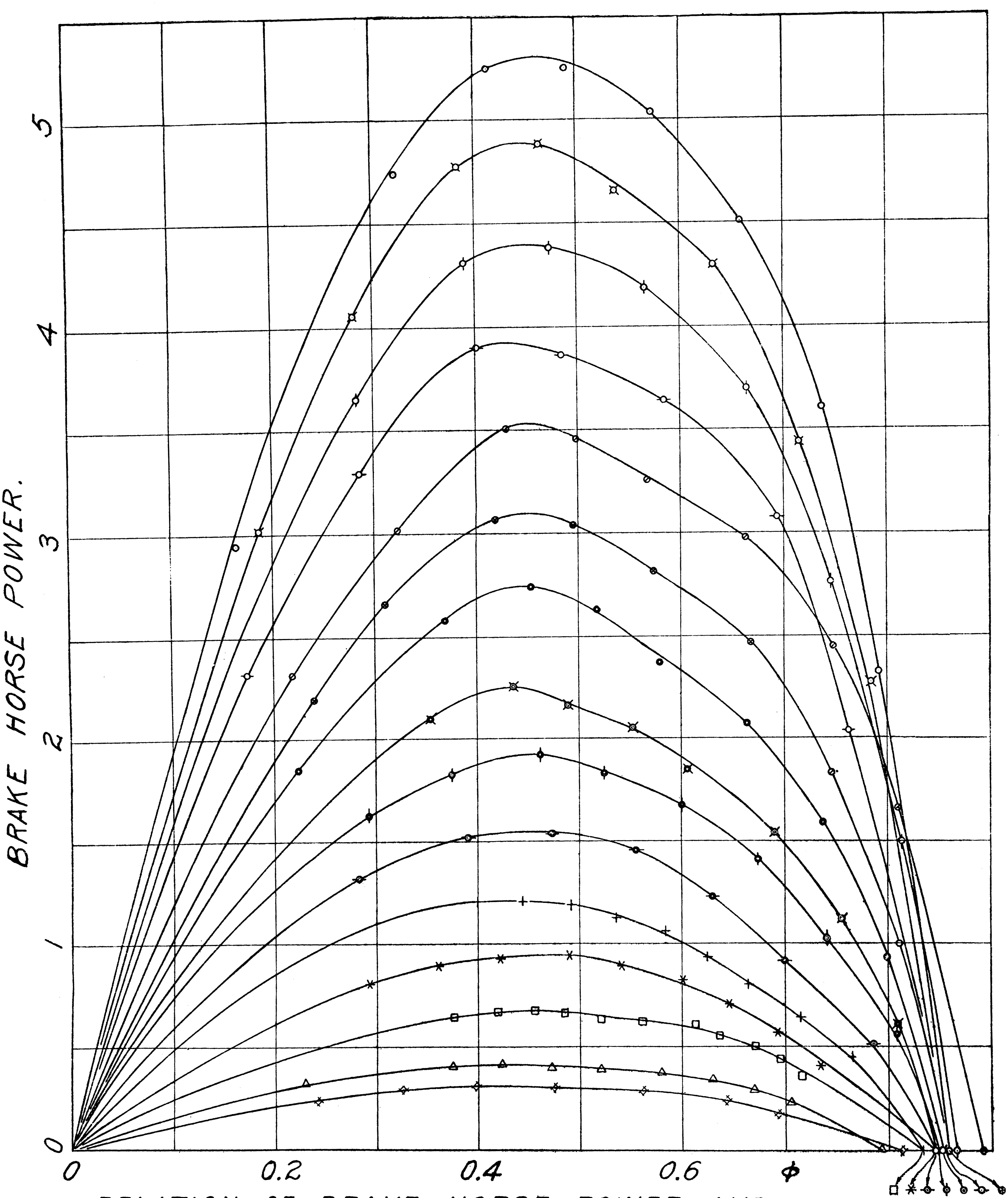
RELATION OF EFFICIENCY TO RATIO OF PERIPHERAL

FIG. 2.



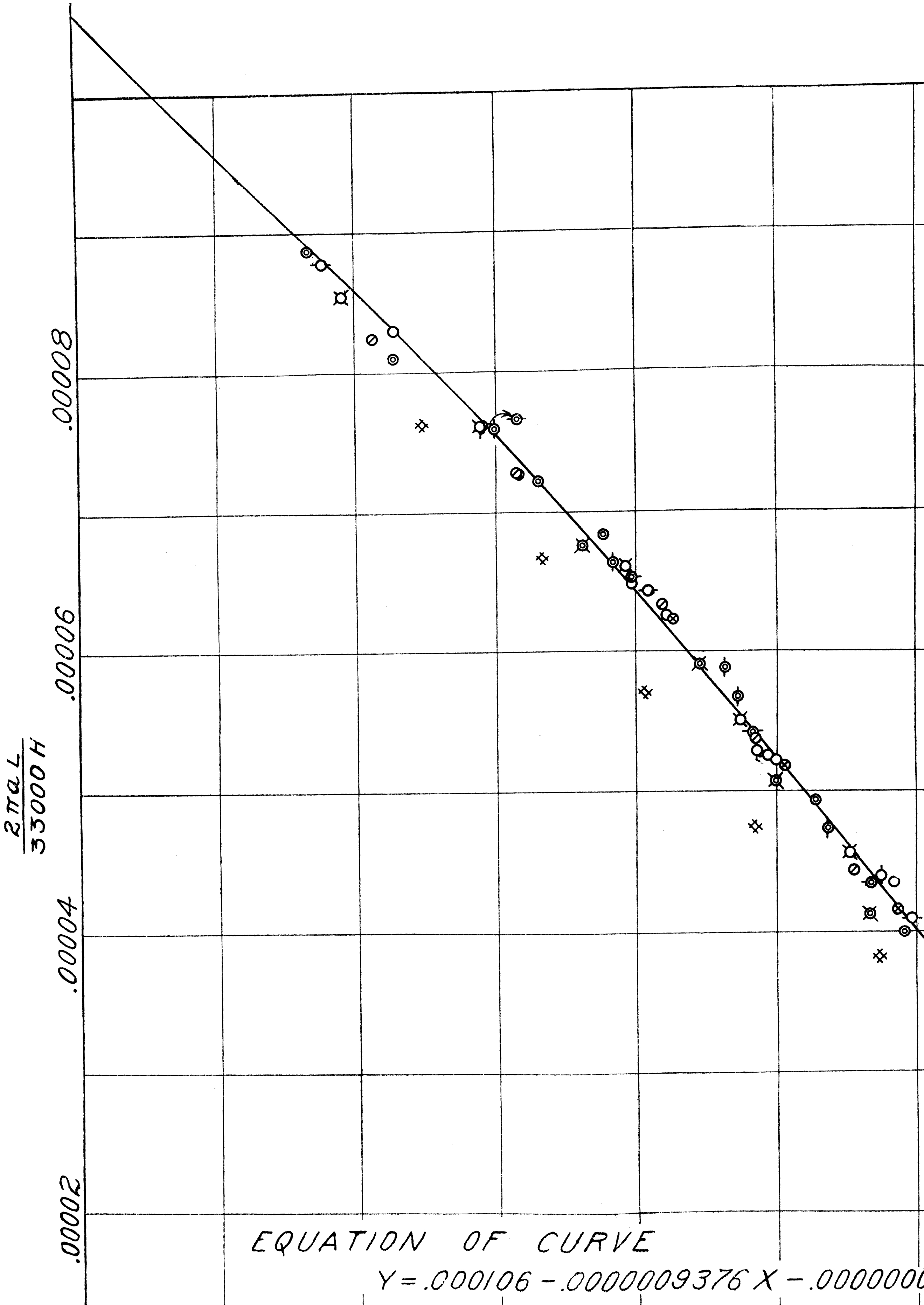
NCY TO RATIO OF PERIPHERAL VELOCITY TO $\sqrt{2gh}$.

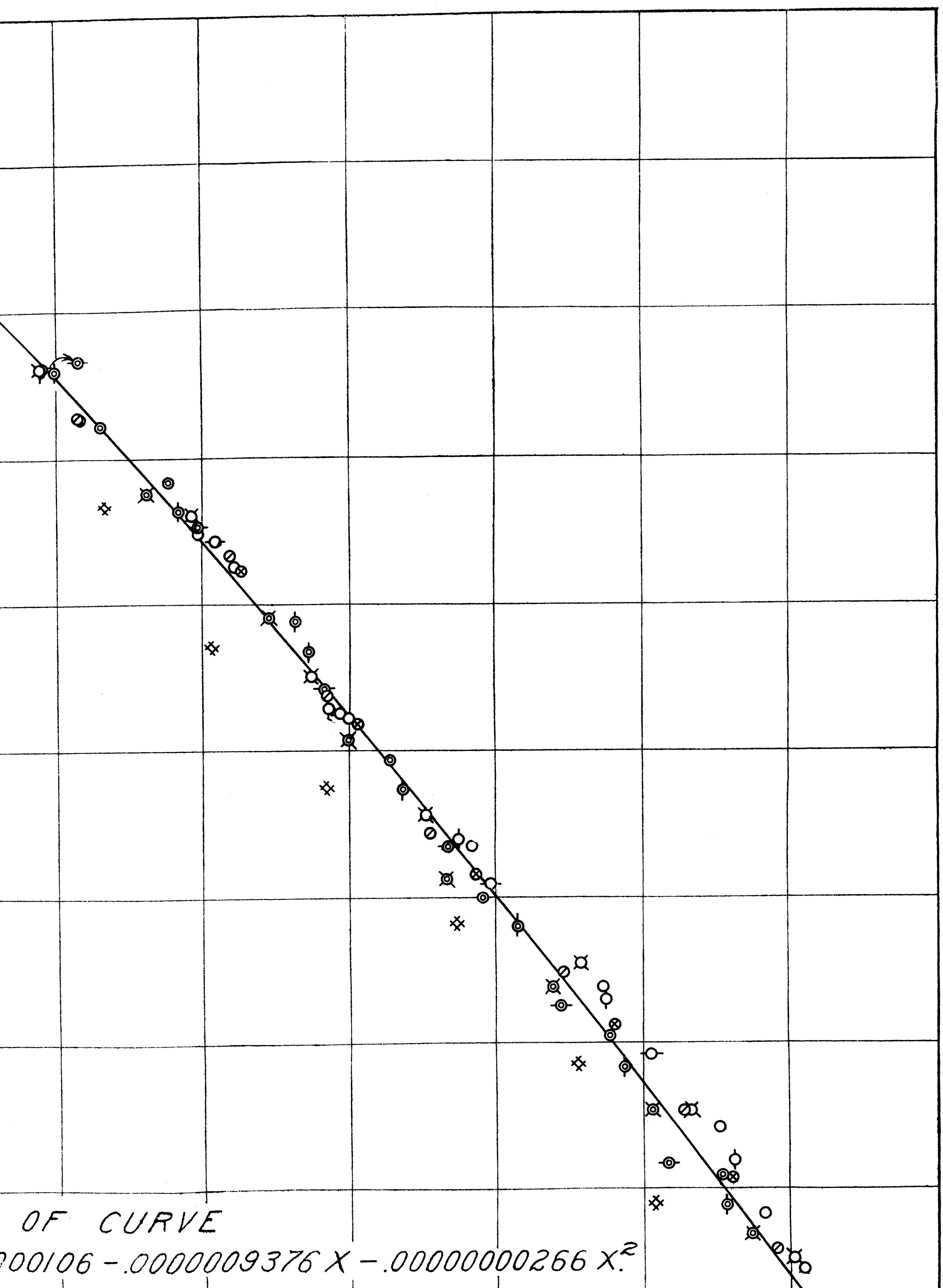
FIG. 2.

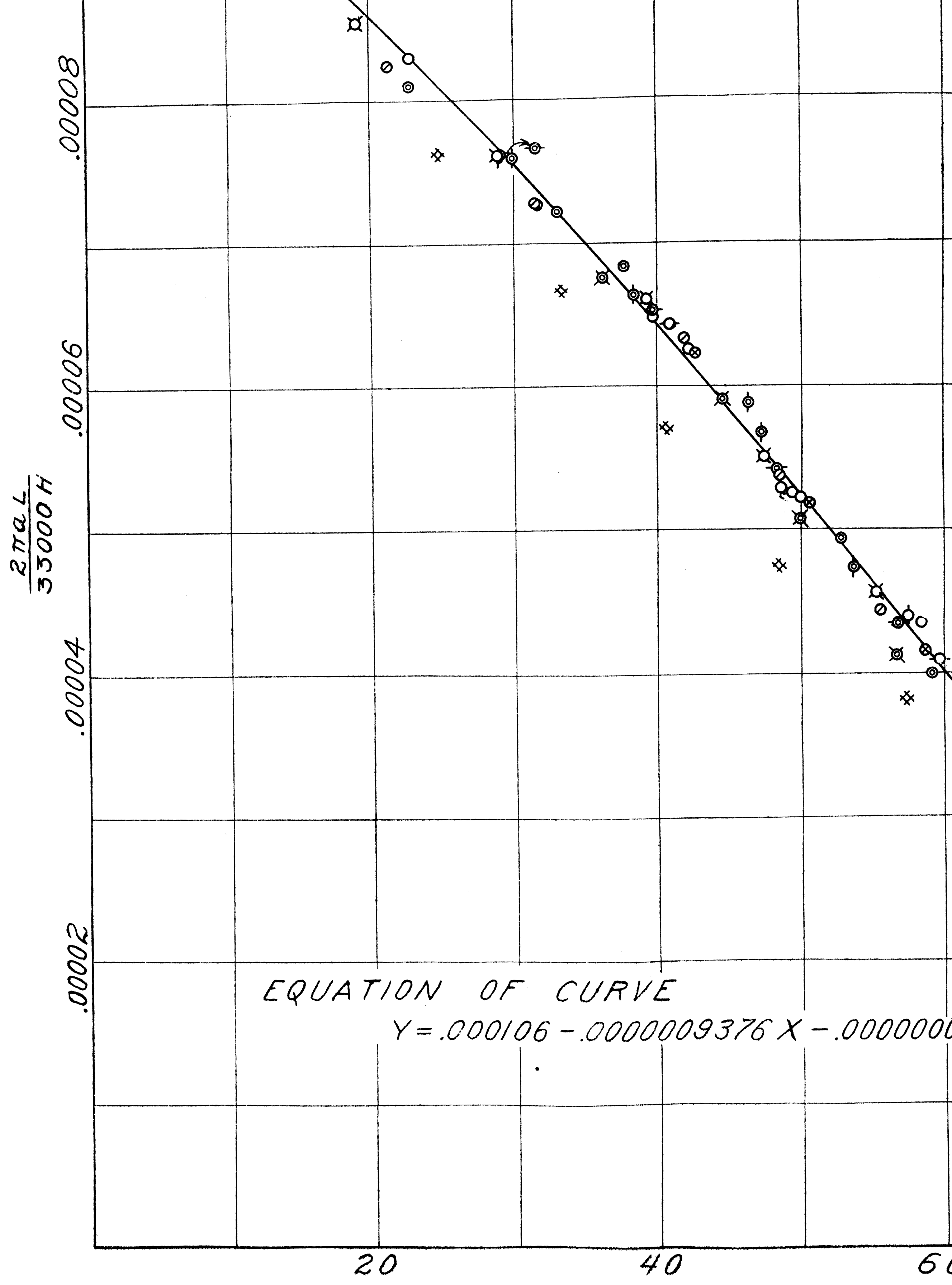


RELATION OF BRAKE HORSE POWER AND
RATIO OF. PERIPHERAL VELOCITY TO $\sqrt{2gh}$

FIG.-3.

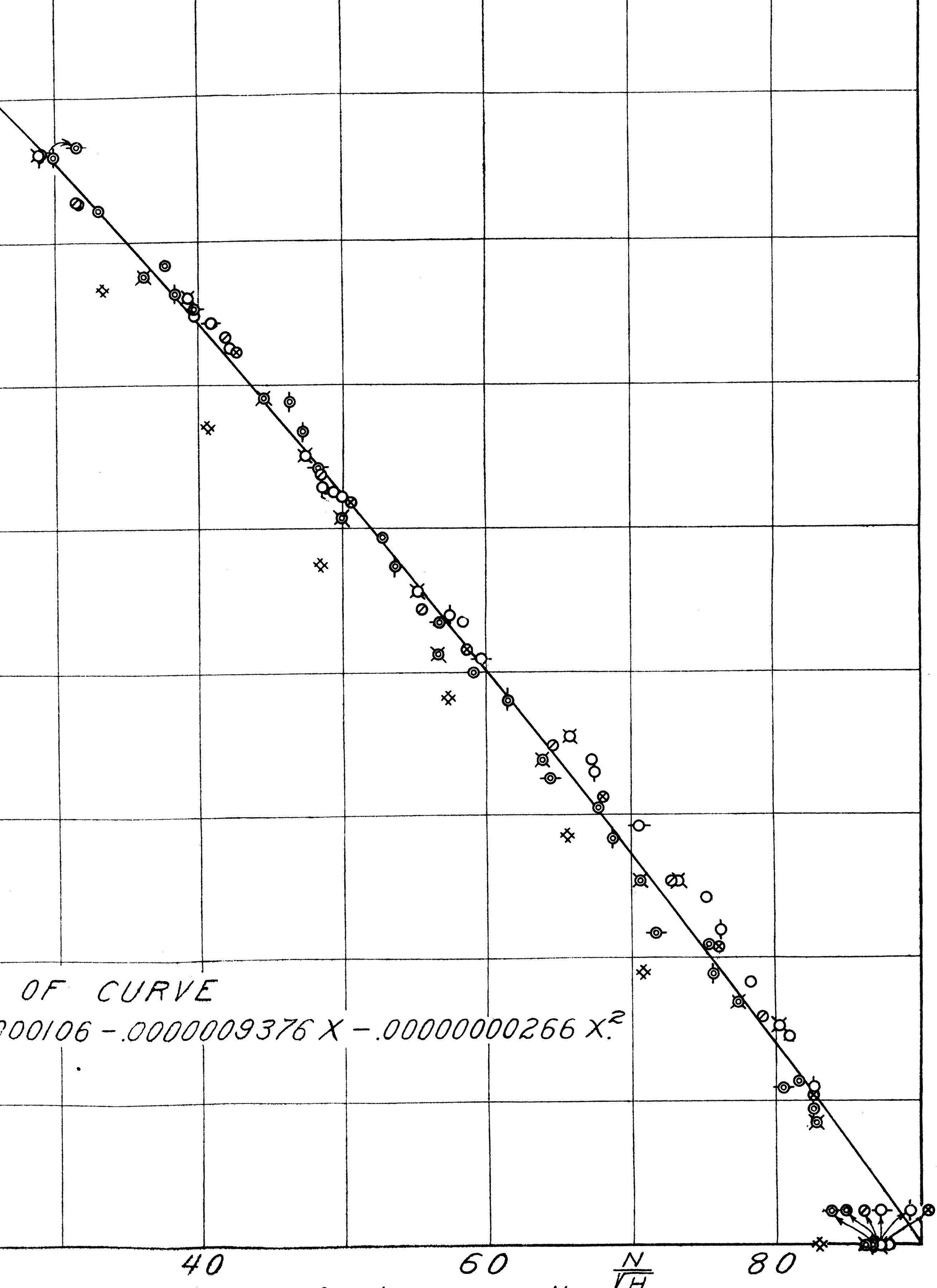

.00008
.00006
.00004
.00002
2πaL / 33000 H
EQUATION OF CURVE
Y = .000106 − .0000009376 X − .000000


OF CURVE
00106 -.0000009376 X -.00000000266 X²



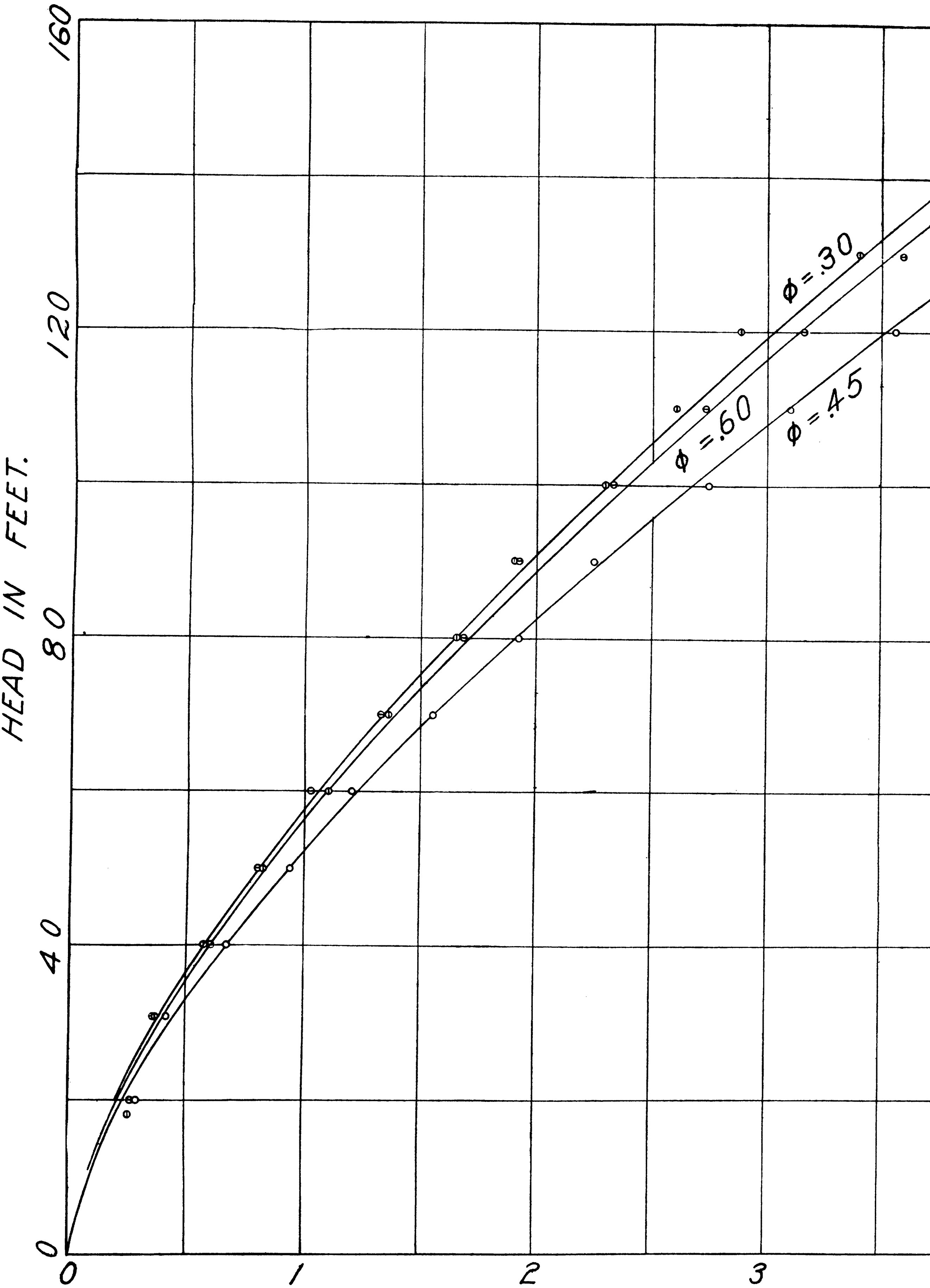
CURVE BETWEEN $\frac{2\pi aL}{33000H}$ AND

FIG. 6.

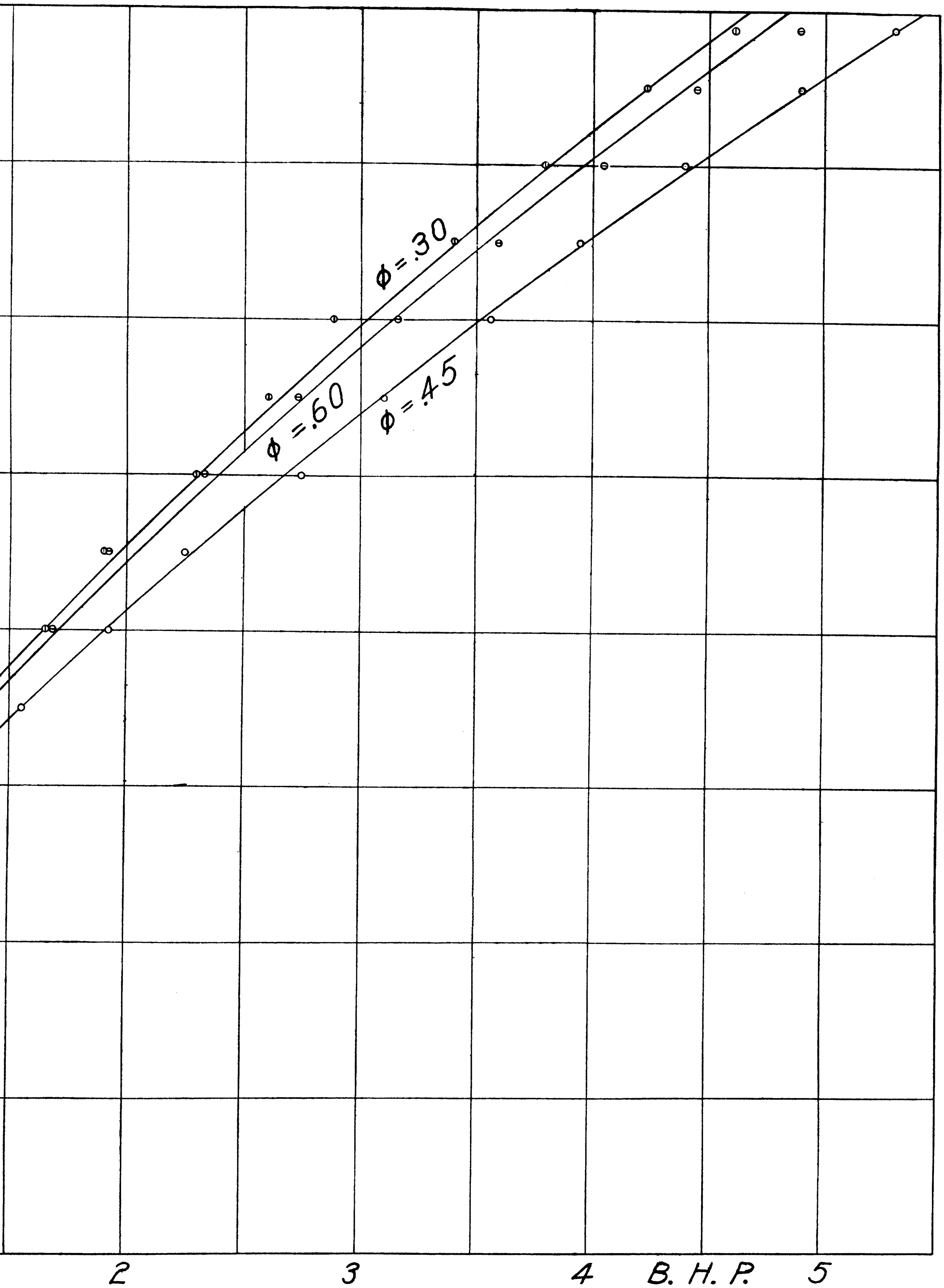


URVE BETWEEN $\frac{2\pi a L}{33000 H}$ AND $\frac{N}{\sqrt{H}}$

FIG. 6.



HEAD IN FEET.
160
120
80
40
0
0
1
2
3
ϕ = .30
ϕ = .60
ϕ = .45


φ = .30
φ = .60
φ = .45
2
3
4
B. H. P.
5

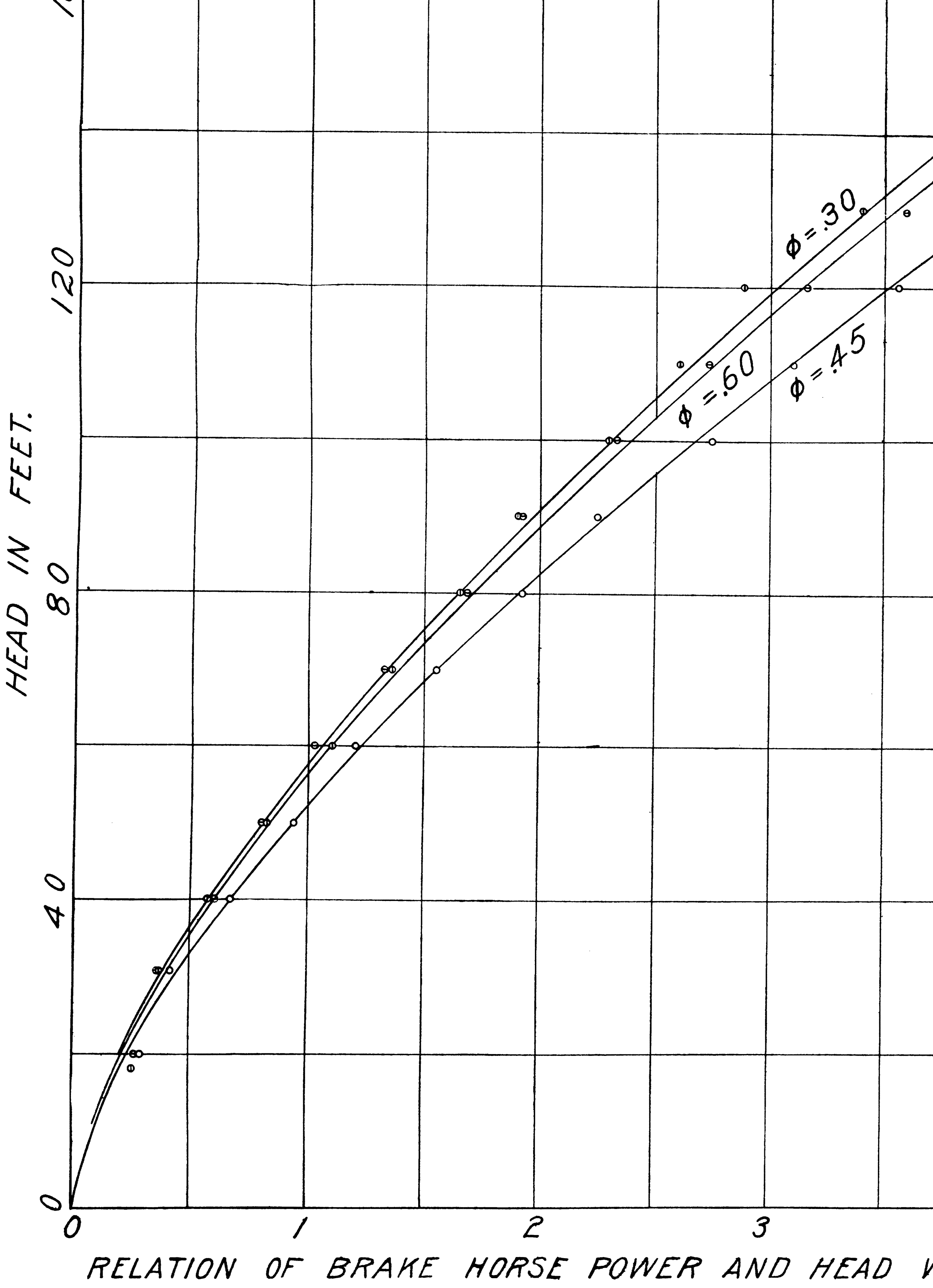
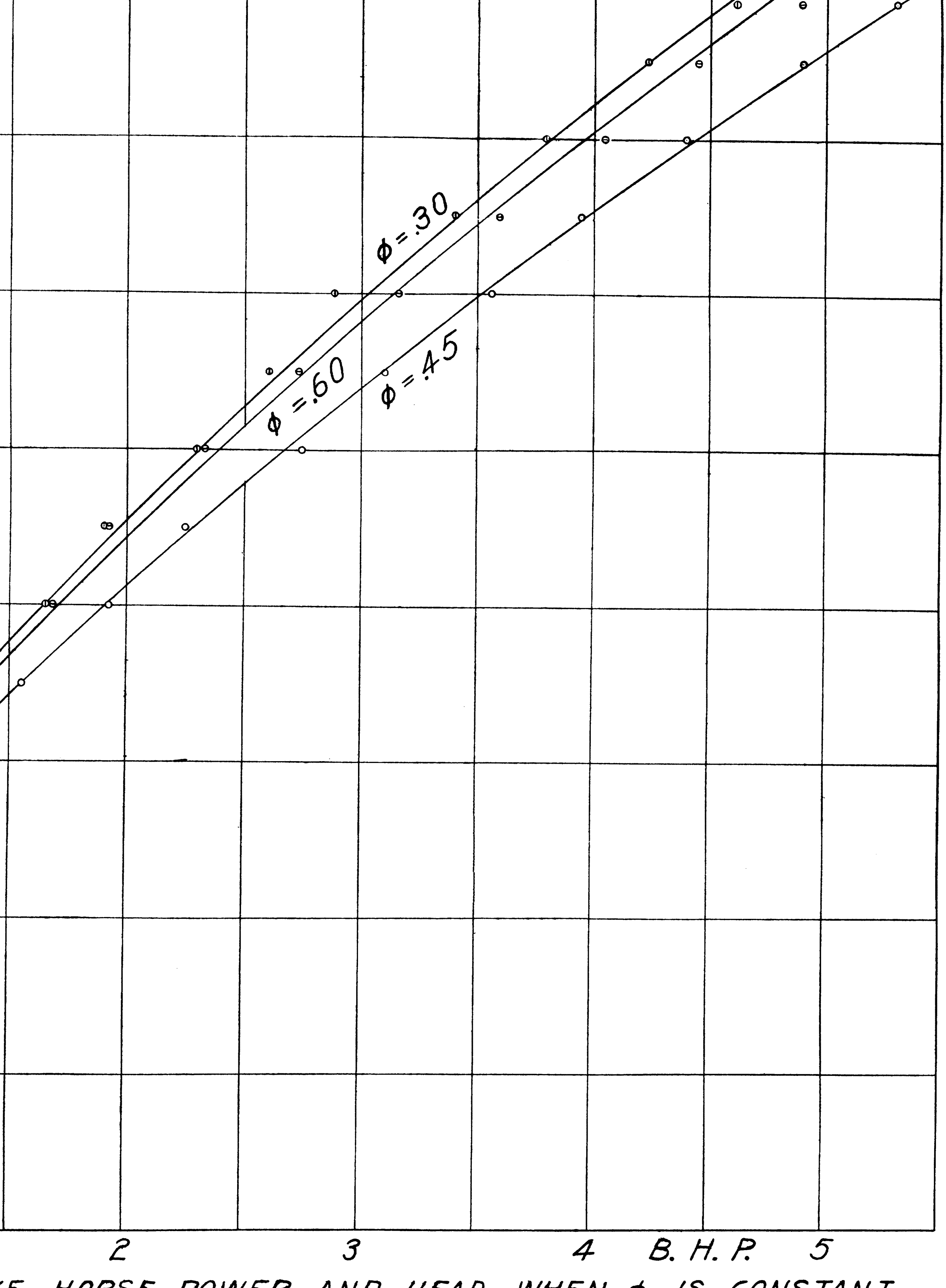

HEAD IN FEET.
0
40
80
120
0
1
2
3
φ = .30
φ = .60
φ = .45
RELATION OF BRAKE HORSE POWER AND HEAD W

FIG. 4.



E HORSE POWER AND HEAD WHEN φ IS CONSTANT.

FIG. 4.

rence of explosions, and what conditions may render them impossible.

The points covered were as follows: *First*, the method of mining. The answers to this question confirmed the common belief that explosions in long-wall mines are almost unknown. Our records show only two cases. *Second*, the method of ventilation. This question was asked with the idea of learning whether the method of ventilation and the amount of air circulated in the mine have any direct bearing upon the question. *Third*, the presence or absence of gas. This question was asked with the idea of determining whether explosions ever occur in mines in which the presence of methane is not revealed by the ordinary methods of examination. *Fourth*, the presence or absence of dust in the mine. The answers to this question were expected to show to some extent the relation of coal-dust to explosions. It was recognized, however, that the replies would not be entirely satisfactory, because it is only very recently that the possibility of dust explosions has been widely recognized. *Fifth*, the presence or absence of water. This question was asked for the purpose of learning whether explosions have occurred in wet mines—that is, mines in which dust was not dry enough to float in the air. *Sixth*, the explosive used. This question was asked for the purpose of learning what, if any, connection might exist between the employment of explosives and the occurrence of explosions. As will be shown later, the connection may be a very intimate one. Besides these specific questions, others were asked which were intended to cover any points which might not have been covered in the preceding questions, so that all the conditions might be learned as far as it is possible to learn them by this method.

In addition to this a very large amount of literature has been read, and abstracts have been made of the valuable parts. The American literature on the subject has been quite thoroughly canvassed and a considerable amount of work has been done on the English, French and German publications. It was learned by this investigation that much of the supposed knowledge of the subject was not substantiated by such proof as to make it trustworthy, and certain experimental work has been done to positively demonstrate what was already believed to be true.

The lines followed in the experimental work were determined by the conditions of the industry in this country. These conditions are so well known that they may be dismissed with a word. Almost all of the coal mined in this country is obtained by the

room-and-pillar method, or some of its modifications. In this method the coal is broken down, not by the weight of the overlying strata, but by the use of explosives; and in American mining as now carried on explosives are used in very large quantities. A few years ago one can of powder weighing twenty-five pounds would frequently last two miners for a period of two weeks, and some of the powder would often be spoiled by dampness before it could be used. At the present time, in the fields of the Middle West, two miners commonly use from five to seven cans of powder in two weeks. The explosive used is almost entirely black blasting-powder, the so-called safety powders having been introduced to only a limited extent.

It was thought that the gases given off by the combustion of this powder might be contributory to some of the explosions which have been recorded. It is now also well known that the dust of some coals when suspended in air under certain conditions is explosive. The experiments then have been conducted principally along two lines—an investigation of coal-dust and an investigation of the gaseous combustion products of black blasting-powder.

A third series of investigations, which may be regarded as accessory to the other two, was an investigation of the explosive qualities of various gases in the form of simple mixtures with air, and of complex mixtures of gases and air. The gases used were such as are found in mines or in the combustion products of black powder, and the tests have made possible the prediction of the explosive or non-explosive quality of different mixtures which may be found in the mine atmosphere.

The behavior of gas mixtures has been tested under various conditions. It has been found that the presence or absence of water vapor makes a practically inappreciable difference. It has also been found that increased pressure causes little, if any, change in the explosiveness of the gases tested. In these experiments the gases were ignited by a flame, by a heated platinum wire, and by an electric spark.

The experiments on the explosive qualities of coal-dust have included a test of the dust of all coals which could be obtained, in which the explosive or non-explosive character of the dust when mixed with air was determined; and also the amount of dust which it was necessary to suspend in the air in order to make the mixture explosive. Other substances besides coal-dust have also been tested. These dusts were tested by placing them in a small box having a rotating fan in the bottom. Ignition was made in most cases by

the application of a flame. It was found that some dusts are much more explosive than others, and that when the dust is produced by pulverizing coal the least friable portion of the coal is the most explosive. The samples of the more and less friable portions have been examined under the microscope and the size of the individual grains measured, and it has been found that the more explosive portion contains a large portion of very fine grains, averaging about 0 003 of a millimeter in diameter, while the less explosive portion consists mostly of larger grains. By most explosive it is meant that a lower proportion of coal-dust to air is explosive. It will be seen that the surface of a grain 0.003 of a millimeter in diameter is very large in comparison with the volume, and that the opportunity for the occlusion of gases is very favorable; and also that such a grain could be heated in a very short time to the point at which gases would be distilled.

In the case of the only sample which has been obtained which had not been exposed to the air for an appreciable length of time it was found that the dust was not explosive, but that after about four hours' exposure to the atmosphere it became explosive. This sample was from the state mine at Lansing, and consisted of drill dust taken from the solid coal, none of which came from coal lying within three feet of the exposed face. Dust made by grinding lumps of this coal which had been exposed for a considerable time had been previously found to be explosive. When this fresh dust was collected it was sealed in a metal can. The can was so opened as to collect any gas which might have been given off by the coal. No such gas was found. Investigations are now under way to determine what change takes place in the coal during its exposure to the atmosphere. These investigations are incomplete, but show that oxygen is absorbed from the air. This absorption takes place even under a negative head of six inches of mercury.

The explosiveness of some of the dusts has also been tested in the presence of small quantities of natural gas, and it has been found that in some cases, in which both the gas and the dust are present in quantities too small for either one alone to be explosive, the combination is explosive. The same test was made using carbon monoxid and the same result obtained. It is therefore evident that the presence of even a small amount of explosive dust may be a source of great danger in case the mine air should contain a small amount of natural gas, or of combustible gases from any other source. And it should be noted that the safety-lamp which is commonly used for testing for gas indicates nothing less than about

two per cent. of gas; and that even this amount is recognized only in case the observer has keen eyes.

Tests have also been made to determine what, if any, gases could be withdrawn from the coal-dusts by placing them under a negative pressure. The results so far are negative, though it is believed that some coals would yield gases under such conditions. Gases driven off from the coal by increases in temperature have also been examined. The temperatures used were much below those used in the manufacture of coal-gas, the idea of the experiments being to determine what gases might be derived from coal-dust under such an increase of temperature as might be found under certain conditions in a mine; for instance, such as might be caused by the passage of a wave of compression of mine air into a blind passage.

The examination of explosives has been confined thus far to the black blasting-powder, which is the explosive most commonly used in American coal-mining. Its composition is approximately—

Sodium nitrate	73 per cent.
Sulfur	11 "
Charcoal	16 "

It is well known that the gaseous decomposition products of black powder contain carbon dioxid, nitrogen, carbon monoxid, methane, hydrogen and sulfuretted hydrogen, and sometimes small amounts of other gases, and that the combustible gases mentioned sometimes constitute a sufficient percentage of the whole gaseous mixture to make this mixture combustible. It was thought that this fact might have an important bearing on the subject, and a series of experiments have been conducted for the purpose of determining the gaseous products of the decomposition of black blasting-powder as it is now manufactured and the conditions under which large quantities of combustible gases are produced.

Our search of the literature of the subject disclosed the fact that no investigation along this line had been so conducted as to give its results any considerable value. The best work on the subject of black powder has been almost entirely confined to the study of gunpowder, which consists of potassium nitrate, sulfur and charcoal. Correspondence with the principal powder manufacturers of this country and some of Europe showed only that little was known of the action of black powder or of the conditions necessary to the production of large quantities of combustible gases. It is generally assumed that the substitution of sodium nitrate for saltpeter has no other effect on the powder than to make it more susceptible to damage by moisture in the air. This fact has prevented its suc-

cessful manufacture and use in England, but it is believed that no potassium nitrate black powders are used in this country. Apparently it is a fact that the use of sodium nitrate makes no important difference in the gaseous decomposition products.

The most careful examination of the decomposition products of gunpowder are those made by Abel and Noble of England and published in 1875 and 1880. Their experiments seemed to indicate, though not very conclusively, that the percentage of carbon monoxid decreases as the percentage of the volume of the containing vessel occupied by the powder increases; or, in other words, as the density of the products of composition increases. If this is the case, it would seem that the products of a blown-out shot in which the powder burns without doing much mechanical work should contain a comparatively large amount of carbon monoxid.

In order to test this point and others, a large number of experiments have been carried on. Powder has been burned in three different ways: First, by dropping the grains into a heated iron tube so arranged that the gases could be collected. This gave the gases at nearly atmospheric pressure. Second, by placing a considerable quantity in an iron tube and igniting it by means of a fuse, the gases being collected in a larger tube for the purpose of excluding air. This gives conditions approaching those of a blow-out shot. Third, by exploding the powder in a gas-tight bomb from which the gases could be drawn off as desired. The experiments have not confirmed the results indicated by the experiments of Abel and Noble, in that apparently the percentage of carbon monoxid does not decrease as the density of the composition products increases, but the change, if any, is in the opposite direction. The series of experiments is hardly sufficiently extended to make it advisable to give this as a positive statement, but the experiments so far conducted indicate this. It is sometimes stated that mining powder gives as much as thirty-three per cent. of carbon monoxid. If this statement is true, it evidently refers to the mining powder which has sometimes been used in England and which differs from gunpowder in the reduction of the percentage of saltpeter, and not to mining powder as used in the United States, which is fully nitrated, and gives about seven to ten per cent. of carbon monoxid.

To determine as far as possible the effect of coal upon the gaseous products of the powder, coal in the form of fine dust and in the form of larger grains has been mixed with the powder. It was found that carbon monoxid, methane and hydrogen appeared in greatly increased quantities, and that, in some cases, the gaseous

mixture would burn in the air. It is therefore evident that black powder, if used in a mine under such conditions as to produce large quantities of combustible gases, may be a source of great danger, especially if the mine contains explosive dust. The importance of the method of mining is evident in connection with this point. In the room-and-pillar method and its modifications from one to three shots are fired in one room. The gases evolved are therefore mixed at first with only a small quantity of air, and if these gases contain a sufficient quantity of combustibles an explosive mixture may result, while if the powder gases were mixed with a larger quantity of air the mixture would not be explosive. Explosions of mixtures of powder gases and air formed under these conditions are of frequent occurrence and may give rise to explosions of great importance.

The production of carbon monoxid during mine fires should also be mentioned, as some explosions have undoubtedly been due to the presence of carbon monoxid thus produced. A severe explosion at Hanna, Wyo., was apparently caused in this way.

As stated previously, the work is not finished, and this is to be regarded only as a preliminary report, not stating final conclusions, but constituting a record of progress. It is intended that this investigation shall be continued until as many as possible of the problems connected with it shall have been attacked and, it is hoped, solved. It is recognized that the question is a complicated one and that it deserves all of the serious attention which it is now receiving. The canvass of the literature of the subject will be continued with the idea of compiling as complete a bibliography as is possible. The laboratory experiments will be continued, especially along the lines of the investigation of coal-dust and of explosives. Up to the present time nothing but black blasting-powder has been studied. It is our desire to make a study also of the safety powders now being placed upon the market. It is also our intention to carry on a set of investigations at mines, testing the action of the explosives in actual use and examining the mine atmosphere.